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FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 64-46

SUPPLEMENTARY STUDY OF DESIGN FACTORS IN AIR DELIVERY FOR CV-7 CARIBOU AIRCRAFT

Task 1D643324D59806

August 1964

U.S. ARMY MOBILITY COMMAND

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SUPPLEMENTARY STUDY OF DESIGN FACTORS IN AIR DELIVERY FOR CV-7 CARIBOU AIRCRAFT

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CONTENTS

SYMBOLS

Alphabetical Character	FORTRAN Character	
AM	AM	length of pallet or load
DE	DE	arbitrary interval of time between successive points in solution of a differential equation
g		acceleration due to gravity
G		center of gravity
HG	HG	height of center of gravity of load above floor
HH	HH	height of load if rectangular; otherwise, length of perpendicular from any point on upper side of load above floor
I_G		moment of inertia of load about horizontal axis through center of gravity, perpendicular to line of flight
L		sill of ramp in horizontal (i.e., up) position
q	Q	distance between mid-point of underside of load and sill of ramp, measured positively when mid-point is rear of sill
q	QD	first derivative of q with respect to time
t		time
W		weight of load in gravitational units

Alphabetical Character	FORTRAN Character	
x_{st}	XST	distance from bulkhead of forward face of load or forward edge of pallet when motion starts
x_G y_G	XG YG	coordinates of center of gravity of load with respect to horizontal and vertical axes through L x_G measured positively rearward y_G measured positively upward
θ	T or TH	angle through which load has turned from original horizontal position; denoted by T in two-degree phase and by TH in three-degree phase
$\dot{\theta}$	TD or THD	first derivative of θ with respect to time; denoted by TD in two-degree phase and by THD in three-degree phase
$\ddot{\theta}$	TDD	second derivative of θ with respect to time
μ	YU	coefficient of sliding friction between floor and load or pallet
R		force of reaction of sill on load or pallet in gravitational units
	DIST	distance traveled by load at constant acceleration during one-degree-of freedom phase

SUMMARY

A study is made of the extraction of loads by parachute from the CV-7 Caribou aircraft. Two FORTRAN programs are included (see Appendix II) to show the calculation of the maximum safe envelope for the loads; various conditions with a wide range of adjustable parameters are considered. In the programs, the parameters may be set as data to simulate any values, such as those for the extractive force of the ejection parachute, for the coefficient of sliding friction between the floor and the load, and for the length of the pallet on which the load is mounted.

The conclusions reached are negative in character, but they can be of value as a basis for further studies. The load tips so little at the sill of the floor with the ramp up that the maximum safe envelope departs only slightly from the rectangular form. It is believed that the effects of gust disturbances and of possible jamming in the rail restraint and release system should be investigated, since, from time to time, these influences will cause the load to tip through angles of inclination of a higher order of magnitude than those due to dynamical considerations.

CONCLUSIONS

Computations for this study were based on a 216-inch-long pallet, which is the longest rectangle contemplated and the most likely to reveal the effects of tipping. In no case did the four safe envelopes computed show a departure of more than 7 inches between the minimum and the maximum height permissible. Therefore, it is concluded that:

1. Further study should include the extent of gust disturbance on load trajectory. (This study would be in addition to carrying out experimental work to determine photographically, or otherwise, the trajectory of such a pallet.)

2. The effects of jamming in the rail restraint and release system should be investigated by means of a nonexperimental method: the FORTRAN data parameters could be adjusted so that the load would have a velocity rearward of almost zero when tipping starts.

INTRODUCTION

The study discussed in this report is a continuation of one presented in TRECOM Technical Report 63-71, "Study of Design Factors in Air Delivery for CV-7 Caribou Aircraft", which was published by the U. S. Army Transportation Research Command at Fort Eustis, Virginia, in December 1963. The earlier report dealt with the motion of containers loaded in the cargo compartment of aircraft when the containers are extracted by parachute. In this report, consideration is given to the effects of friction between the load and the floor of the cargo compartment and to the downward-sloping configuration of the roof over the double-hinged door at the rear of the cargo compartment; also in this report, it is assumed that the force of extraction drops to zero as soon as tipping starts at the sill of the ramp.

In the previous report, the force of extraction was assumed to be 1.5 times that due to gravity, a value which is considerably higher than that indicated by experiments conducted at the Air Force Flight Test Center, Edwards Air Force Base, California, where it was found that when the parachute was unopened, the force built up from zero value to a maximum which lay between .3 and .8.*

These much lower values for the extracting force result in the attainment of increased angles of inclination of the load to the horizontal, and this, in turn, produces contours for maximum safe envelopes which are no longer uniform in height. The lower the extracting force and the greater the coefficient of sliding friction, the more marked this effect becomes. Four contours for maximum safe envelopes have been calculated for the 216-inch-long pallet for typical values of such parameters as the coefficient of friction, the extracting force, the height of the roof from the sill,

*Universal Cargo Handling System for C-130 Aircraft, Technical Documentary Report No. 62-27, Air Force Flight Test Center, Edwards Air Force Base, California.

and the starting station of the pallet. The contours of three of the envelopes are shown graphically in Appendix I. The results for two of the four envelopes differed so slightly that one graph represents both envelopes; the only two differences between the two envelopes are shown with the graph.

This report also shows the need to determine experimentally the radius of gyration around a horizontal axis through the center of gravity of a load such as the 105mm howitzer mounted on a 216-inch pallet.

In TRECOM Technical Report 63-71, the general equations of motion of the load during the two-degrees-of-freedom phase were derived by Lagrange's method. Owing to the presence of friction, which makes the system nonconservative, Lagrange's method was not followed in the present study. Instead, the forces of reaction and of friction have been included as external forces on the load. One angular momentum equation and two linear acceleration-force equations are derived; these equations yield two differential equations for q and θ and also one for R, the reaction.

Appendix IV has been added to show how the maximum safe height of a rectangular load can be calculated. FORTRAN Program Number Three has been included in this appendix to show the calculation for rectangular loads starting from any station. The data shown at the foot of FORTRAN Program Number Three refer to a 54-inch container starting from station 291 as in Loading Plan 2.

In the analysis of the one-, two-, and three-degrees-of-freedom motion, differential equations must first be obtained for the generalized coordinates that define the configuration of the load at any time; then, these values of the coordinates are used to find whether any given portion of the load hits the horizontal or the downward-sloping portion of the roof.

A general program is constructed that can handle the two- or three-degrees-of-freedom phases of the motion and that during each phase can examine whether either portion of the roof is struck. However, in the majority of cases it is quite unnecessary to use the three-degrees-of-freedom portion of the program; if the load clears the two portions of the roof during the two-degree phase, it clears them also in the three-degree portion of the motion. For this reason, FORTRAN Program Number Two was constructed; it simply examines the two-degrees-of-freedom phase and gives a message on the typewriter as to whether or not the roof is struck.

In both FORTRAN Programs Numbers One and Two, the horizontal and sloping portions of the roof are considered. The height of the horizontal

portion of the roof is read in as data and is normally considered to be 76 inches (82 inches as shown on the manufacturer's drawings less a 6-inch safety margin). The equation in FORTRAN Program Number One for the sloping part of the roof is

$$8.1x + 146.3y - 10884.7 = 0 \tag{1}$$

in relation to the x axis, which extends horizontally through the sill of the ramp, L, and the y axis, which extends vertically through L. The x axis is measured positively to the rear and the y axis positively upward.

The left-hand member of this equation is called SLOP; its being negative indicates that the point represented by (x,y) is on the same side of the sloping roof as the sill, L; when SLOP is positive, point (x,y) is on the side remote from L. In other words, when SLOP is negative, point (x,y) has not touched the roof; when it is positive, the roof has been struck. In the latter case, FORTRAN Program Number Two terminates with the message "STRIKES ROOF". Otherwise, the message "DOES NOT STRIKE ROOF" appears.

In FORTRAN Program Number One, the equation for the sloping portion of the roof, which is indicated in equation (1), does not provide a safety margin of 6 inches. As stated before, a 6-inch safety margin below the horizontal portion of the roof is provided. Therefore, if a 6-inch safety margin is desired under both parts of the roof, SLOP is replaced by the following equation:

$$SLOP = 8.95xCC + 140yCC - 9695.$$

Some of the computer runs have been made with this modified value for SLOP, and the results can be compared with those corresponding to equation (1). The same margin of safety should be provided throughout. The load will be moving faster when passing under the sloping part of the roof, so that the consequences of striking the roof would be more serious.

In FORTRAN Program Number Two, the modified value of SLOP has been inserted.

ONE-DEGREE-OF-FREEDOM MOTION

Figure 1 shows the load moving down the floor of the cargo compartment of the aircraft under the action of the following forces:

P due to the extracting force of the parachute;

W due to the force of gravity of the load itself acting through the center of gravity, G, of the load;

R due to the reaction of the floor on the load;

μR due to friction of the floor on the load.

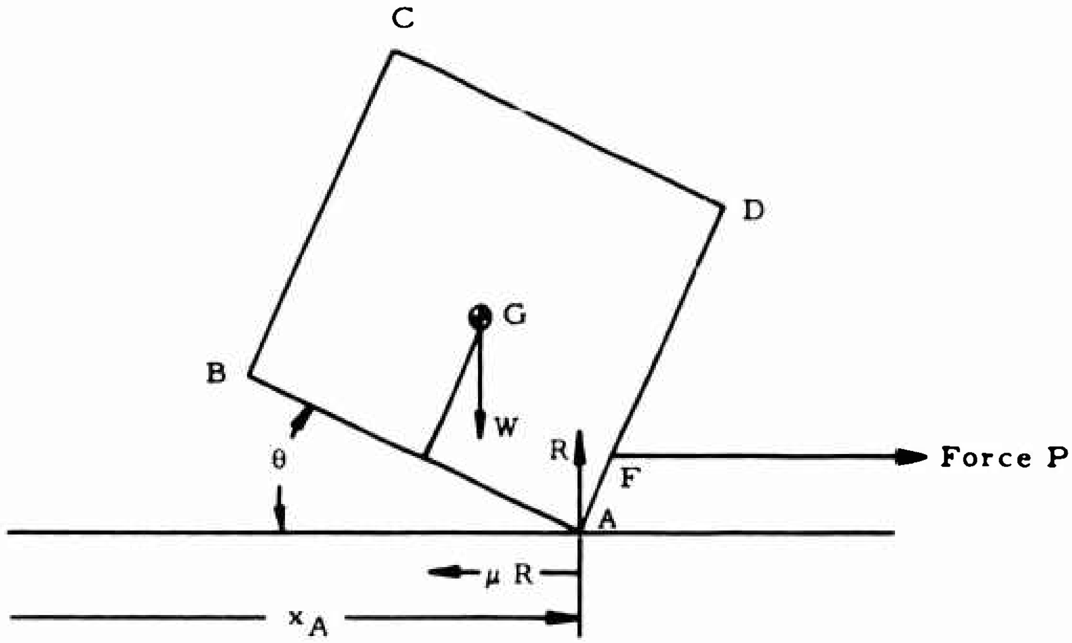


Figure 1. Sketch Illustrating One-Degree-of-Freedom Motion.

The two coordinates, x_A and θ, define the position and configuration of the load with respect to the aircraft. Following is a theorem of wide applicability in the mechanics of a system of particles (which is therefore applicable to a rigid body) that is used to determine the horizontal and vertical components of the acceleration of G: the center of gravity of a system of particles moves as though all the mass and all the external forces were concentrated at the center of gravity.

When the forces are resolved horizontally,

$$P - \mu R = \frac{W}{g} \frac{d^2}{dt^2} \left(x_A - \frac{AM}{2} \cos \theta + HG \sin \theta\right),$$

the quantity in parentheses being equal to the x coordinate of the center of gravity.

If forces are resolved vertically,

$$W - R = \frac{W}{g}\frac{d^2y}{dt^2} = \frac{W}{g}\frac{d^2}{dt^2}\left(\frac{AM}{2}\sin\theta + HG\cos\theta\right).$$

To find the angular acceleration of the load about a horizontal axis through G, a general theorem in the dynamics of a rigid body is again referenced: the rate of change of angular momentum about any axis through the center of gravity is equal to the moment of the external forces about that axis. Hence,

$$\mu R\left(\frac{AM}{2}\sin\theta + HG\cos\theta\right) - R\left(\frac{AM}{2}\cos\theta - HG\sin\theta\right)$$

$$- P\left[\frac{AM}{2}\sin\theta + (HG - HD)\cos\theta\right] = \ddot{\theta}\frac{I_G}{g},$$

When the differentiations are performed, these equations become

$$P - \mu R = \frac{W}{g}\left[\ddot{x}_A + \dot{\theta}^2\left(\frac{AM}{2}\cos\theta - HG\sin\theta\right) + \ddot{\theta}\left(\frac{AM}{2}\sin\theta + HG\cos\theta\right)\right] \quad (2)$$

$$W - R = \frac{W}{g}\left[\dot{\theta}^2\left(\frac{AM}{2}\sin\theta + HG\cos\theta\right) + \ddot{\theta}\left(HG\sin\theta - \frac{AM}{2}\cos\theta\right)\right] \quad (3)$$

$$\mu R\left(\frac{AM}{2}\sin\theta + HG\cos\theta\right) - R\left(\frac{AM}{2}\cos\theta - HG\sin\theta\right)$$

$$- P\left[\frac{AM}{2}\sin\theta + (HG - HD)\cos\theta\right] = \ddot{\theta}\frac{I_G}{g}. \quad (4)$$

In order to find the conditions under which the load will tip about the corner A, let $\theta = 0$ and $\dot{\theta} = 0$. Also set P = W PRO and $I_G = \frac{AM^2 + 4HG^2}{12}$ by the well-known formula for the moment of inertia of a rectangular parallelepiped about an axis through its center of gravity parallel to an axis of figure. If these substitutions are made, the equations become

$$\ddot{\theta} HG \frac{W}{g} + R\mu + \ddot{x}_A \frac{W}{g} = W\ PRO \tag{5}$$

$$-\ddot{\theta} \frac{AM}{2} \frac{W}{g} + R = W \tag{6}$$

$$\ddot{\theta} \frac{W}{g} \left(\frac{AM^2 + 4HG^2}{12} \right) + R\left(\frac{AM}{2} - \mu HG \right) = -W\ PRO(HG - HD)\ . \tag{7}$$

Solving by Cramer's rule for $\ddot{\theta}$,

$$\ddot{\theta} = g \frac{\begin{vmatrix} PRO & \mu & W/g \\ 1 & 1 & 0 \\ -PRO(HG - HD): & \frac{AM}{2} - \mu HG & 0 \end{vmatrix}}{\begin{vmatrix} HG & \mu & W/g \\ \frac{-AM}{2} & 1 & 0 \\ \frac{(AM^2 + 4HG^2)}{12} & \frac{AM}{2} - \mu HG & 0 \end{vmatrix}} \cdot$$

The denominator is negative for all values of AM, PRO, HG, and HD that will be encountered in practice. Hence, the initial value of $\ddot{\theta}$ is positive if the numerator is negative, that is, if

$$\mu HG + PRO\ HD > \frac{AM}{2} + PROHG. \tag{8}$$

Provided this condition is not satisfied, θ and its first two derivatives remain zero until tipping starts at the rear end of the loading ramp during the two-degrees-of-freedom motion. As long as $\ddot{\theta} = 0$, equations (4), (5), and (6) reduce to

$$R\mu + \ddot{x}_A \frac{W}{g} = W\ PRO$$

and

$$R = W,$$

which yields $\ddot{x}_A = g(PRO - \mu)$ as is otherwise evident. (9)

This value of $\ddot{x}_A$ is used in line 16 of FORTRAN Program Number One and in line 15 of FORTRAN Program Number Two to give the value of

QD(1), that is, the initial linear velocity rearward of the load at the start of the two-degrees-of-freedom motion. The load will have enjoyed this constant acceleration since starting from rest with corner B at distance x_{st} from the forward bulkhead until tipping starts when B is at distance $D1 - [\frac{AM}{2} - Q(1)]$ from the bulkhead. The difference, which is called DIST in the FORTRAN programs, between these two distances gives the length of the path traveled at constant acceleration $g(PRO - \mu)$.

TWO-DEGREES-OF-FREEDOM MOTION

As stated earlier, it is assumed in this study that the force of extraction of the parachute becomes zero the moment that tipping starts at the rear end of the loading ramp. Figure 2 shows how the configuration of the system is defined by the two generalized coordinates, q and θ. The three external forces acting on the load are also shown: the force of gravity vertically downward through G; the reaction of the sill on the underside of the load, R, acting normally to the underside; and the force of friction, μR, tangentially to the underside.

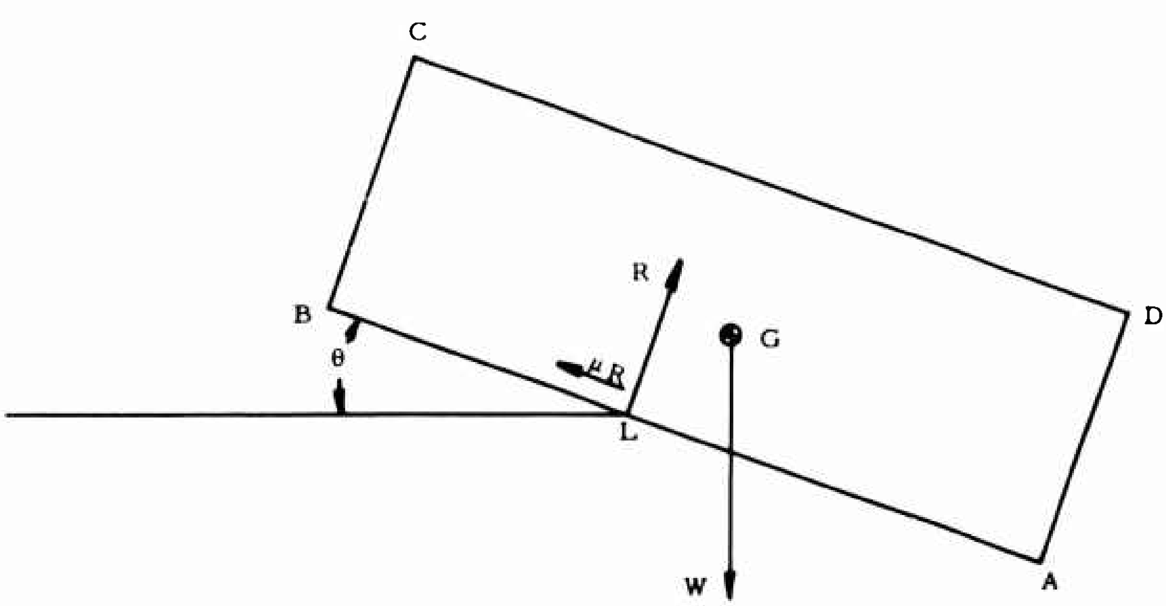


Figure 2. Sketch Illustrating Two-Degrees-of-Freedom Motion.

If the forces are resolved horizontally,

$$-\mu R \cos\theta + R \sin\theta = \frac{W}{g}\frac{d^2}{dt^2}(q \cos\theta + HG \sin\theta) = \frac{W}{g}(\ddot{q} \cos\theta - \dot{q}\dot{\theta}$$

$$\sin\theta - \dot{q}\dot{\theta} \sin\theta - q\dot{\theta}^2 \cos\theta - q\ddot{\theta} \sin\theta - HG\dot{\theta}^2 \sin\theta + HG\ddot{\theta} \cos\theta). \quad (10)$$

If the forces are resolved vertically,

$$W - R \cos\theta - \mu R \sin\theta = -\frac{d^2}{dt^2}(HG \cos\theta - q \sin\theta)$$

$$= -\frac{W}{g}(-HG\dot{\theta}^2 \cos\theta - HG\ddot{\theta} \sin\theta - \ddot{q} \sin\theta$$

$$- 2\dot{q}\dot{\theta} \cos\theta + q\dot{\theta}^2 \sin\theta - q\ddot{\theta} \cos\theta), \quad (11)$$

since vertical coordinates are measured positively upward.

Taking moments about the center of gravity, G,

$$\mu RHG + Rq + I_G \frac{\ddot{\theta}}{g} . \quad (12)$$

Set

$$I_G = W(\frac{AM^2 + 4HG^2}{12}),$$

and arrange equations (10), (11), and (12) as equations in the second derivatives of q and θ ; then in R,

$$\ddot{q} \cos\theta + \ddot{\theta}(HG \cos\theta - q \sin\theta) + \frac{Rg}{W}(\mu \cos\theta - \sin\theta)$$

$$= 2\dot{q}\dot{\theta} \sin\theta + \dot{\theta}^2(q \cos\theta + HG \sin\theta), \quad (13)$$

and

$$\ddot{q} \sin \theta + \ddot{\theta}(HG \sin \theta + q \cos \theta) + \frac{R}{Wg(\cos \theta + \mu \sin \theta)}$$

$$= g - \dot{\theta}^2(HG \cos \theta - q \sin \theta) - 2\dot{q}\dot{\theta} \cos \theta, \quad (14)$$

and

$$\ddot{q}\ 0 + \ddot{\theta}\left(\frac{AM^2 + 4HG^2}{12}\right) - \frac{Rg(q + \mu HG)}{W} = 0 . \quad (15)$$

From this point on, both in the analysis and in the FORTRAN programs, $\frac{R}{W}$ is replaced by R.

Equations (13), (14), and (15) take the following simplified forms:

$$\ddot{q}A1 + \ddot{\theta}A2 + RA3 = A4 \quad (16)$$

$$\ddot{q}B1 + \ddot{\theta}B2 + RB3 = B4 \quad (17)$$

$$\ddot{q}0 + \ddot{\theta}C2 + RC3 = 0 . \quad (18)$$

The following substitutions can be made:

$A1 = \cos \theta$, $A2 = HG \cos \theta - q \sin \theta$, $A3 = g(\mu \cos \theta - \sin \theta)$, and
$A4 = 2\dot{q}\dot{\theta} \sin \theta + \dot{\theta}^2(q \cos \theta + HG \sin \theta)$.

$B1 = \sin \theta$, $B2 = HG \sin \theta + q \cos \theta$, $B3 = g(\cos \theta + \mu \sin \theta)$, and
$B4 = g - \dot{\theta}^2(HG \cos \theta - q \sin \theta) - 2\ \dot{q}\dot{\theta} \cos \theta$.

$C2 = \frac{AM^2 + 4\ HG^2}{12}$ and $C3 = g(-q - \mu HG)$.

Then equations (16), (17), and (18) can be solved for q, θ, and R by Cramer's rule. The 10 quantities A1 to C3 retain their identities in the FORTRAN programs. The values obtained for R must always be positive; this has been tested in all instances.

In FORTRAN Program Number One (see Appendix II), immediately preceding the "51 Continue" statement that closes the first DO loop, the following two "IF" statements appear:

```
   IF (Q(K)-AM/2.) 12,13,45
12 IF (Q(K+1)-AM/2.) 51,14,46 .
```

These statements direct the program to four alternatives, which in each case calculate by simple interpolation the values of $\dot{q}$, θ, and $\dot{\theta}$; these values correspond to $q = \frac{AM}{2}$; that is, to the instant when corner B is at L, the sill of the ramp. These final values of q and of θ and of their first derivatives for the two-degrees-of-freedom motion are used to obtain initial values of coordinates and their velocities in the three-degrees-of-freedom phase.

THREE-DEGREES-OF-FREEDOM MOTION

Immediately after corner B of the load reaches the sill, L, the load assumes three degrees of freedom, the remaining three of the six freedoms enjoyed by a rigid body in space being ankylosed, as explained in TRECOM Technical Report 63-71 on page 1. The only external force acting on the load during the three-degree phase is that of gravity; consequently, the center of gravity, G, executes a parabolic path, and the load continues to turn with uniform angular velocity about a horizontal axis through G.

Let x_G and y_G be the coordinates of G with respect to horizontal and vertical axes through L, x being measured positively aft and y positively upward. Thus, $\ddot{x}_G = 0$ and $\ddot{y}_G = -g$, and on integrating twice with respect to time,

$$x_G = (x_G)_o + t(\dot{x}_G)_o$$

and

$$y_G = (y_G)_o + t(\dot{y}_G)_o - \frac{gt^2}{2}$$

where t seconds have elapsed since corner B was at L. Also, in an obvious notation, $(..)_o$ is used to denote the value of a variable at the

instant when $t = 0$. The final values of q, $\dot{q}$, θ, and $\dot{\theta}$ in the two-degrees-of-freedom phase are denoted by QL, QLD, TL, and TLD.

At any instant in the two-degree phase,

$$x_G = q \cos \theta + HG \sin \theta$$

and

$$\dot{x}_G = \dot{q} \cos \theta - q\dot{\theta} \sin \theta + HG\dot{\theta} \cos \theta.$$

Hence,

$$(x_G)_o = QL \cos TL + HG \sin TL \tag{19}$$

and

$$(\dot{x}_G)_o = QLD \cos TL - QL \sin TL\ TLD + HG\ TLD \cos TL. \tag{20}$$

Similarly,

$$y_G = HG \cos \theta - q \sin \theta.$$

Hence,

$$(y_G)_o = HG \cos TL - QL \sin TL, \tag{21}$$

and

$$\dot{y}_G = -HG\dot{\theta} \sin \theta - \dot{q} \sin \theta - q\dot{\theta} \cos \theta,$$

which in turn yields

$$(\dot{y}_G)_o = -HG \sin TL\ TLD - QLD \sin TL - QL\ TLD \cos TL. \tag{22}$$

In FORTRAN Program Number One, the quantities on the left-hand sides of equations (19) through (22) are referred to as XGO, XGDO, YGO, and YGDO.

In TRECOM Technical Report 63-71, pages 20 through 23, the differential equation

$$\ddot{\phi} = -SS \sin \phi$$

was solved to yield the angle of inclination of the load to the horizontal during the three-degrees-of-freedom phase. However, in our present problem, as previously stated, the extracting force of the parachute becomes zero when tipping at L commences. Hence, the load turns with

uniform angular velocity around G during the three-degrees-of-freedom motion; and the angle of inclination of the load to the horizontal, which is denoted by TH in FORTRAN Program Number One, is found at successive intervals of time by the following FORTRAN equations:

```
TH(J+1) = TH(J) + DE*THD(J)
THD(J+1) = THD(J).
```

In the FORTRAN programs shown in TRECOM Technical Report 63-71, the following expression was incorporated for the moment of inertia of the load around a horizontal axis through its center of gravity:

$$I_G = \frac{AM^2 + 4HG^2}{12}.$$

Using this equation is tantamount to assuming that the load is a rectangular parallelepiped of length AM and height 2HG. While this is a fair approximation for cargo loaded into a container, the expression is far from exact for an irregular object such as a 105mm howitzer, which has much of its weight concentrated around its center of gravity. For this reason, in FORTRAN Programs Numbers One and Two the quantity C2, which is the moment of inertia in equations (16) through (18), is reduced by an arbitrary proportion that in the sample program in Appendix II is taken as 0.6. While this is an arbitrary and inexact method of estimating the moment of inertia, it is the best way available until actual experiments are conducted to determine this quantity. The moment of inertia of such a load could be determined by timing its periods of oscillation around a series of axes that are parallel to, and at varying distances from, the load's center of gravity.

The quantity C2 has been further modified to correspond to a proportion of .4 times that for a uniform rectangular load in certain of the computer results; in this case the angle of inclination, θ , of the load increases more rapidly. In all of the graphical results of the computer runs and in the corresponding tables of the values of HH and AN, the proportion assumed for modifying C2 is clearly stated.

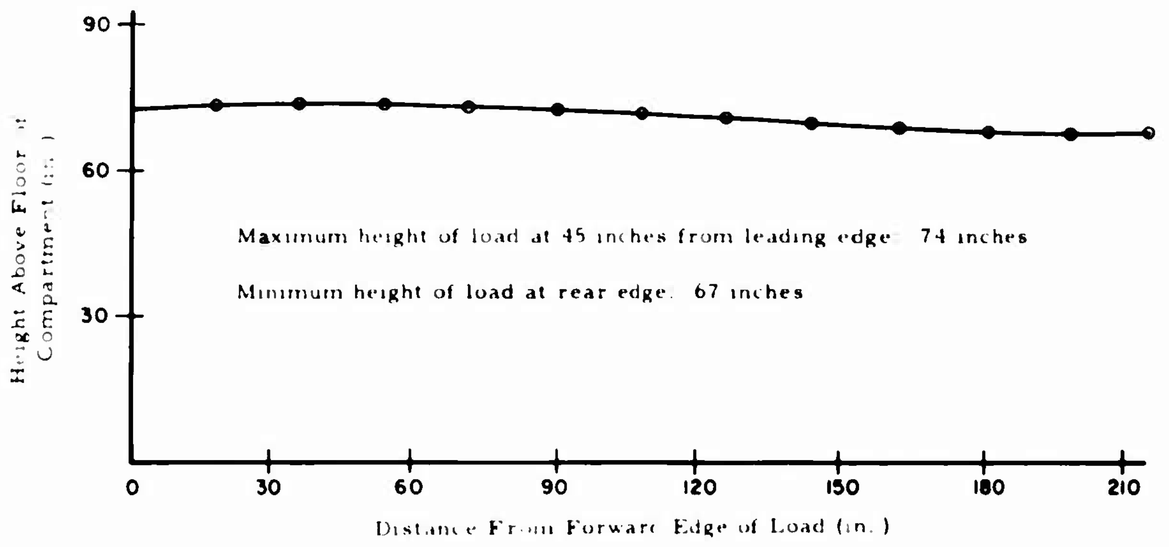
APPENDIX I

MAXIMUM SAFE ENVELOPES

PARAMETERS

- Accelerative force is .4 times that of gravity.
- Coefficient of friction is .05.
- Distance from bulkhead when load starts moving with forward face is 78 inches.
- Length of pallet on which load is mounted is 216 inches.
- Center of gravity of load is 20 inches above mid-point of pallet.
- Safety margin provided below horizontal part of roof is 6 inches; no safety margin is provided below sloping part of roof.
- Moment of inertia of load is .6 times that of rectangular load of same dimensions.

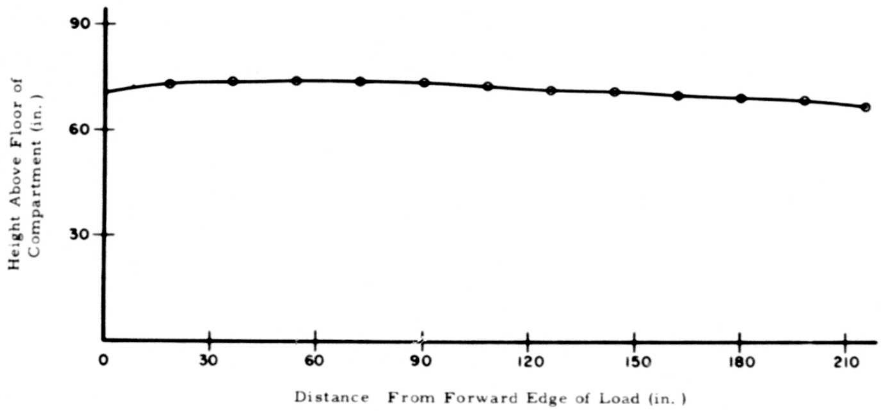
DISTANCE FROM FORWARD FACE OF LOAD (In.)	HEIGHT ABOVE FLOOR (In.)
0	73
18	73
36	74
54	74
72	73
90	73
108	72
126	72
144	71
162	70
180	69
198	68
216	67



PARAMETERS

Accelerative force is .25 times that of gravity.
Coefficient of friction is .05.
Distance from bulkhead when load starts moving with forward face is 78 inches.
Length of pallet on which load is mounted is 216 inches.
Center of gravity of load is 20 inches above mid-point of pallet.
Safety margin provided below horizontal part of roof is 6 inches; no safety margin is provided below sloping part of roof.
Moment of inertia of load is .6 times that of rectangular load of same dimensions.

DISTANCE FROM FORWARD FACE OF LOAD (In.)	HEIGHT ABOVE FLOOR (In.)
0	71
18	73
36	73
54	74
72	74
90	73
108	73
126	72
144	71
162	70
180	69
198	68
216	67

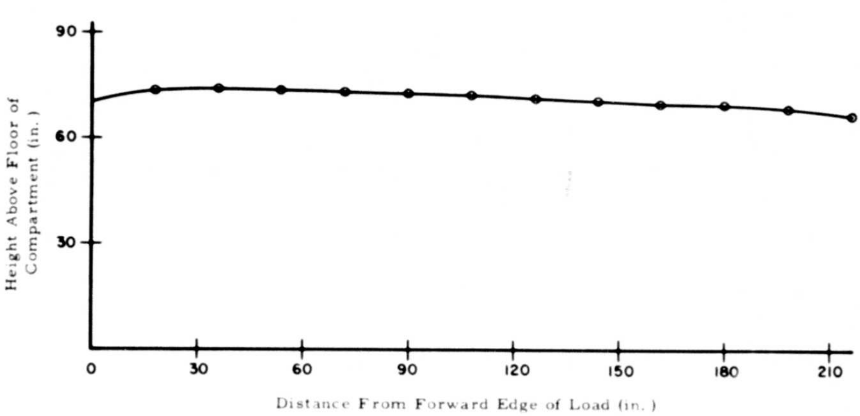


PARAMETERS*

Accelerative force is .25 times that of gravity.
Coefficient of friction is .05.
Distance from bulkhead when load starts moving with forward face is 22 inches.
Length of pallet on which load is mounted is 216 inches.
Center of gravity of load is 20 inches above mid-point of pallet.
Safety margin provided below horizontal part of roof is 6 inches; no safety margin is provided below sloping part of roof.
Moment of inertia of load is .6 times that of rectangular load of same dimensions.

DISTANCE FROM FORWARD FACE OF LOAD (In.)	HEIGHT ABOVE FLOOR (In.)
0	71
18	73
36	74
54	74
72	74
90	73
108	73
126	72
144	71
162	70
180	69
198	68
216	67

* Results from the fourth envelope differed in only the following respects: (1) the moment of inertia for the fourth envelope was .4 (rather than .6) times that of a rectangular load of the same dimensions; and (2) when there was a distance of 36 inches from the forward face of the load, the height above the floor was 73 (rather than 74) inches.



APPENDIX II

FORTRAN PROGRAMS

PROGRAM NUMBER ONE

```
C     CARIBOU    WITH FRICTION
      DIMENSION T(100),TD(100),TDD(100),Q(100),QD(100),QDD(100),R(100)
      DIMENSION TH(45),THD(45),THDD(45)
      READ 1,PRO
      READ 1,YU
      READ 1,DE
      READ 2,D1
      READ2,XST
      READ2,AM
      READ 2,HH
      READ 3,AN
      READ 2,HG
      READ 2,ROOF
      Q(1)=-YU*HG
      DIST=D1-XST-AM/2.+Q(1)
      QD(1)=SQRT(773.8*(PRO-YU)*DIST)
      T(1)=.0
      TD(1)=.0
      C2=(AM**2+4.*HG**2)/12.
      C2=.6*C2
      DO 51 K=1,65
      A1=COS(T(K))
      A2=HG*COS(T(K))-(Q(K))*SIN(T(K))
      A3=386.4*(YU*COS(T(K))-SIN(T(K)))
      A5=2.*(QD(K))*(TD(K))*SIN(T(K))
      A6=((TD(K))**2)*((Q(K))*COS(T(K))+HG*SIN(T(K)))
      A4=A5+A6
      B1=SIN(T(K))
      B2=HG*SIN(T(K))+(Q(K))*(COS(T(K)))
      B3=(COS(T(K))+YU*SIN(T(K)))*386.4
      B5=386.4-((TD(K))**2)*(HG*COS(T(K))-(Q(K))*SIN(T(K)))
      B6=-2.*(QD(K))*(TD(K))*COS(T(K))
      B4=B5+B6
      C3=-386.4*(Q(K)+YU*HG)
      DET=A1*(B2*C3-B3*C2)-A2*B1*C3+A3*B1*C2
      QDD(K)=(A4*(B2*C3-C2*B3)-A2*B4*C3+A3*B4*C2)/DET
      TDD(K)=(A1*B4*C3)/DET
      R(K)=(-A1*B4*C2+A4*B1*C2)/DET
      XCC=HH*SIN(T(K))-(AN-Q(K))*COS(T(K))
      YCC=HH*COS(T(K))+(AN-Q(K))*SIN(T(K))
      SLOP=XCC*8.1+YCC*146.3-10884.7
      IF (ROOF-YCC) 61,61,53
   53 IF (SLOP) 54,61,61
   54 CONTINUE
      Q(K+1)=Q(K)+DE*QD(K)+((DE**2)/2.)*QDD(K)
      T(K+1)=T(K)+DE*TD(K)+((DE**2)/2.)*TDD(K)
      TD(K+1)=TD(K)+DE*TDD(K)
      QD(K+1)=QD(K)+DE*QDD(K)
      IF (Q(K)-AM/2.) 12,13,45
   12 IF (Q(K+1)-AM/2.) 51,14,46
   51 CONTINUE
   13 CONTINUE
```

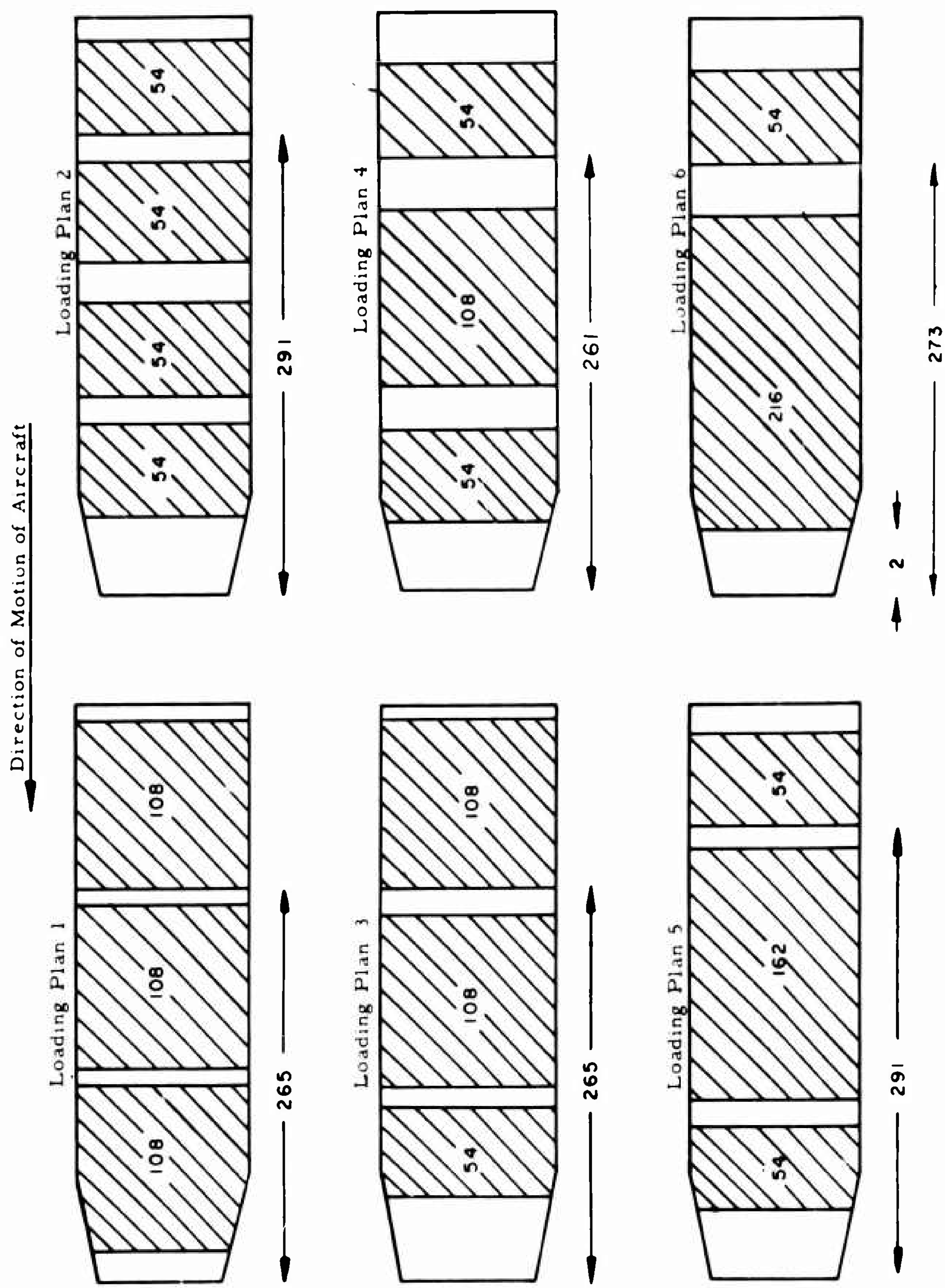
```
C     Q(K) COINCIDES WITH SILL OF FLOOR
   99 QL= AM/2.
      QLD=QD(K)
      TL=T(K)
      TLD=TD(K)
      GO TO 49
   45 CONTINUE
C     SILL IS BETWEEN Q(K-1) AND Q(K)
C     WE FIND TM THE TIME FROM INSTANT K-1 TILL LOAD CLEARS FLOOR
   98 TM =DE*(AM/2.-Q(K-1))/(Q(K)-Q(K-1))
      QL=AM/2.
      QLD=QD(K-1)+TM*QDD(K-1)
      TL= T(K-1)+TM*TD(K-1)+(TM**2)*(TDD(K-1))/2.
      TLD=TD(K-1)+TM*TDD(K-1)
      GO TO 49
   14 CONTINUE
C     Q(K+1) COINCIDES WITH SILL OF FLOOR
   97 QL=AM/2.
      QLD=QD(K+1)
      TL =T(K+1)
      TLD =TD(K+1)
      GO TO 49
   46 CONTINUE
C     SILL IS BETWEEN Q(K) AND Q(K+1)
C     WE FIND TM, THE TIME FROM INSTANT K TILL LOAD CLEARS FLOOR
   96 TM = DE*(AM/2.-Q(K))/(Q(K+1)-Q(K))
      QL= AM/2.
      QLD=QD(K)+TM*QDD(K)
      TL= T(K)+ TM*TD(K) +(TM**2)*(TDD(K))/2.
      TLD = TD(K) + TM*TDD(K)
   49 CONTINUE
      TH(1)=TL
      THD(1)=TLD
   59 DO 61 J=1,40
      TP=J
      TIM = DE*TP
      XGO=QL*COS(TL)+HG*SIN(TL)
      XGDO=QLD*COS(TL)+TLD*(-QL*SIN(TL)+HG*COS(TL))
      YGO=-QL*SIN(TL)+HG*COS(TL)
      YGDO=-QLD*SIN(TL)-TLD*(QL*COS(TL)+HG*SIN(TL))
      XG=XGO+XGDO*TIM
      YG=YGO+YGDO*TIM-((386.4*(TIM)**2)/2.)
      XC=XG-AN*COS(TH(J))+(HH-HG)*SIN(TH(J))
      YC=YG+AN*SIN(TH(J))+(HH-HG)*COS(TH(J))
      PRINT 7,J,XC,YC
      PAUSE
      TH(J+1)=TH(J)+DE*THD(J)
      THD(J+1)=THD(J)
   61 CONTINUE
      STOP
    1 FORMAT (F3.2)
    2 FORMAT (F5.1)
    3 FORMAT (F6.1)
    7 FORMAT (I4,3X E14.8,3X E14.8)
      END
```

PROGRAM NUMBER TWO

```
C      CARIBOU    WITH FRICTION
       DIMENSION T(100),TD(100),TDD(100),Q(100),QD(100),QDD(100),R(100)
       READ 1,PRO
       READ 1,YU
       READ 1,DE
       READ 2,D1
       READ 2,XST
       READ 2,AM
       READ 2,HH
       READ 3,AN
       READ 2,HG
       READ 2,ROOF
       Q(1)=-YU*HG
       DIST=D1-XST-AM/2.+Q(1)
       QD(1)=SQRT(773.8*(PRO-YU)*DIST)
       T(1)=.0
       TD(1)=.0
       C2=(AM**2+4.*HG**2)/12.
       C2=.6*C2
       DO 51 K=1,99
       A1=COS(T(K))
       A2=HG*COS(T(K))-(Q(K))*SIN(T(K))
       A3=386.4*(YU*COS(T(K))-SIN(T(K)))
       A5=2.*(QD(K))*(TD(K))*SIN(T(K))
       A6=((TD(K))**2)*((Q(K))*COS(T(K))+HG*SIN(T(K)))
       A4=A5+A6
       B1=SIN(T(K))
       B2=HG*SIN(T(K))+(Q(K))*(COS(T(K)))
       B3=(COS(T(K))+YU*SIN(T(K)))*386.4
       B5=386.4-((TD(K))**2)*(HG*COS(T(K))-(Q(K))*SIN(T(K)))
       B6=-2.*(QD(K))*(TD(K))*COS(T(K))
       B4=B5+B6
       C3=-386.4*(Q(K)+YU*HG)
       DET=A1*(B2*C3-B3*C2)-A2*B1*C3+A3*B1*C2
       QDD(K)=(A4*(B2*C3-C2*B3)-A2*B4*C3+A3*B4*C2)/DET
       TDD(K)=(A1*B4*C3)/DET
       XCC=HH*SIN(T(K))-(AN-Q(K))*COS(T(K))
       YCC=HH*COS(T(K))+(AN-Q(K))*SIN(T(K))
       SLOP=XCC*8.95 +YCC*140.0-9695.0
       IF (ROOF-YCC) 61,61,53
   53  IF (SLOP) 54,61,61
   54  CONTINUE
       Q(K+1)=Q(K)+DE*QD(K)+((DE**2)/2.)*QDD(K)
       T(K+1)=T(K)+DE*TD(K)+((DE**2)/2.)*TDD(K)
       TD(K+1)=TD(K)+DE*TDD(K)
       QD(K+1)=QD(K)+DE*QDD(K)
       IF (Q(K)-AM/2.) 51,51,71
   51  CONTINUE
   71  PRINT 11
       GO TO 41
   61  PRINT 12
   41  CONTINUE
       STOP
    1  FORMAT (F3.2)
    2  FORMAT (F5.1)
    3  FORMAT (F6.1)
   11  FORMAT (21H DOES NOT STRIKE ROOF)
   12  FORMAT (13H STRIKES ROOF)
       END
```

APPENDIX III

CARIBOU LOADING PLANS



APPENDIX IV

MAXIMUM SAFE HEIGHT OF RECTANGULAR LOAD

The maximum height for a 54-inch-long container, starting from rest with the forward face at station 291, as in Loading Plan 2, can be found by using FORTRAN Programs Numbers One and Two, taking the least height corresponding to any value of AN.

Exactly the same result is found if FORTRAN Program Number Three (shown below) is used. First, the program is run in abridged form from line 1 to the statement "51 CONTINUE", with a print-out for Q(K), which reveals that Q(16) is the first Q to exceed $\frac{AM}{2}$. Accordingly, the second part of the program, that is, from "51 CONTINUE" to "END", is run with the upper value 16 for index K, as follows:

DO 54 K = 1, 16.

The message "STRIKES ROOF" is given with M = 7 and HH(M) = 68. This shows that 67 inches is the maximum safe height for a 54-inch-long container starting from station 291.

FORTRAN PROGRAM NUMBER THREE

```
FORTRAN PROGRAM NUMBER THREE

C       CARIBOU FOR 54 INCH LOAD
        DIMENSION T(50),TD(50),TDD(50),Q(50),QD(50),QDD(50)
        DIMENSION HH(30),AN(13)
        READ 1,PRO
        READ 1,YU
        READ 1,DE
        READ 2,D1
        READ 2,XST
        READ 2,AM
        READ 2,HG
        READ 2,ROOF
        Q(1)=-YU*HG
        DIST=D1-XST-AM/2.+Q(1)
        QD(1)=SQRT(773.8*(PRO-YU)*DIST)
        T(1)=.0
        TD(1)=.0
        C2=(AM**2+4.*HG**2)/12.
        DO 51 K=1,48
        A1=COS(T(K))
        A2=HG*COS(T(K))-(Q(K))*SIN(T(K))
```

```
      A3=386.4*(YU*COS(T(K))-SIN(T(K)))
      A5=2.*(QD(K))*(TD(K))*SIN(T(K))
      A6=((TD(K))**2)*((Q(K))*COS(T(K))+HG*SIN(T(K)))
      A4=A5+A6
      B1=SIN(T(K))
      B2=HG*SIN(T(K))+(Q(K))*COS(T(K))
      B3=(COS(T(K))+YU*SIN(T(K)))*386.4
      B5=386.4-((TD(K))**2)*(HG*COS(T(K))-(Q(K))*SIN(T(K)))
      B6=-2.*(QD(K))*(TD(K))*COS(T(K))
      B4=B5+B6
      C3=-386.4*(Q(K)+YU*HG)
      DET=A1*(B2*C3-B3*C2)-A2*B1*C3+A3*B1*C2
      QDD(K)=(A4*(B2*C3-C2*B3)-A2*B4*C3+A3*B4*C2)/DET
      TDD(K)=(A1*B4*C3)/DET
      Q(K+1)=Q(K)+DE*QD(K)+((DE**2)/2.)*QDD(K)
      T(K+1)=T(K)+DE*TD(K)+((DE**2)/2.)*TDD(K)
      TD(K+1)=TD(K)+DE*TDD(K)
      QD(K+1)=QD(K)+DE*QDD(K)
      IF (Q(K)-AM/2.) 51,51,58
   51 CONTINUE
   58 CONTINUE
      HH(1)=62.0
      DO 56 M=1,25
      AN(1)=27.0
      DO 55 J=1,10
      DO 54 K=1,16
      XCC=HH(M)*SIN(T(K))-(AN(J)-Q(K))*COS(T(K))
      YCC=HH(M)*COS(T(K))+(AN(J)-Q(K))*SIN(T(K))
      SLOP=XCC*8.95+YCC*140.0-9695.0
      IF (ROOF-YCC) 61,61,53
   53 IF (SLOP) 54,61,61
   54 CONTINUE
      AN(J+1)=AN(J)-6.0
   55 CONTINUE
      HH(M+1)=HH(M)+1.0
   56 CONTINUE
      PRINT 11
      GO TO 41
   61 PRINT 12
   41 CONTINUE
      PRINT 5,M,HH(M)
      STOP
    1 FORMAT (F3.2)
    2 FORMAT (F5.1)
    5 FORMAT (I5,5X E14.8)
   11 FORMAT (21H DOES NOT STRIKE ROOF)
   12 FORMAT (13H STRIKES ROOF)
      END


.40
.05
.01
450.0
291.0
054.0
000.0
076.0
```

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UNCLASSIFIED Report

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3. Maximum Safe Cargo Envelope, CV-7 Caribou Aircraft

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by parachute from the cargo compartment of a CV-7 Caribou aircraft. These equations were solved on an IBM 1620 computer, and the solutions were used to calculate the maximum safe envelope that could be extracted without striking the roof of the cargo compartment. In the present study, consideration is given to friction between the load and the floor of the cargo compartment and to the downward slope of the roof of the aircraft. Lower values of the extracting force are assumed.

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